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RAIL TRANSPORT PERFORMANCES ON ELECTRIFIED AND NON-ELECTRIFIED RAILWAY LINES: SUSTAINABLE RAIL TRANSPORT POINT OF VIEW

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Abstract

Rail transport is considered an environmentally friendly mode of transport. However, this statement is valid if the transport takes place on electrified lines. In 2021, 56% of the total railway network in European countries was electrified. This share has been gradually increasing in recent years. However, the level of electrification of the railway network varies significantly between countries. Switzerland is the only country with a fully electrified rail network, while Kosovo has the only railway network where no tracks are electrified. Eight countries have a rail network in which 70% or more of the tracks are electrified. The first three places are Switzerland (100%), Luxembourg (97%), and Belgium (88%). In seven countries, the level of electrification is below a third of the total railway network (Denmark, Estonia, Ireland, Kosovo, Lithuania, Latvia, and Greece). IRG Rail also started collecting data on the intensity of electrified and non-electrified railway lines use. The first results show that the intensity of electrified network use is higher in all monitored countries. In several countries, the intensity of electrified railway lines use is several times higher compared to non-electrified lines (IRG-Rail. Eleventh Annual Market Monitoring Report). The paper deals with a comparative analysis of traffic performance on electrified and non-electrified railway lines in EU countries for passenger and freight transport. Our research was focused on the share of power of dependent and independent traction, and especially on the share of power of independent traction on electrified lines. We dealt not only with the statistical analysis of performance but primarily with the social costs (internal and external costs) of independent traction in comparison with dependent traction.

Keywords: sustainable rail transport, external costs, diesel traction, electric traction, electrified lines

1 Introduction

Rail transport, as well as other transport modes, must contribute to the global effort to reduce CO_2 emissions as well as to the European goals declared in the European Green Deal and the Recovery Plan. One of the most important steps towards achieving this goal is the use of electric traction. Electric traction is not only more environmentally friendly but also more economically efficient compared to diesel traction. In the event that electricity is produced using renewable sources or in nuclear power plants, CO_2 emissions when using electrified railway lines are minimal.

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Unfortunately, many railway lines are not electrified, even though the intensity of their use is at an average level. In addition, carriers often use diesel locomotives on electrified lines in the event that the transport session runs partly on an electrified and partly on a non-electrified railway line. Therefore, in our research, we focused on what the share of electrified lines is in EU countries and what the performance of electrified lines is, and we examined these performances in the Slovak Republic more closely and also from the external costs point of view.

2 Literature review

Today, more than half of Europe's railway lines are electrified. The analysis carried out in Italy focused on the feasibility of electrifying selected lines where the services are currently operated by diesel trains. The analysis also takes into account the economic aspects related to the construction of the fixed installations that will enable the electrification of the line, as well as the return on the costs incurred for the construction. Research from the point of view of a railway infrastructure manager found that steam and diesel traction are not very efficient [1]. Departure and Letrouvé, in their analysis, compared the energy performance of several railway tractions. They compared hybrid-diesel trains, battery trains, and fuel cell trains. For example, one of the results was saving energy by approximately 20% in hybrid trains [2]. Andrzejewski et al. explored in their article new train drives, which are more ecological than modern drives. They dealt with the last technical solutions on vehicle drives. The analysis contained hybrid vehicles and hydrogen drives. The author pointed out the feasibility and efficiency of using some drives from several points of view [3].

Pugi pointed to situations when the electrification of lines is very difficult or, on some lines, impossible for various reasons. The author pointed to the utilization of hybrid vehicles, which combine electric drive and battery drive. On the electrified parts of lines, the train uses catenary lines to drive and recharge batteries on the train. In long distances between electrified parts of lines, it is possible to build recharge stations. The battery may be recharged when the train brakes uses recuperation [4]. Chamaret et al. point to the large number of non-electrified lines in the EU and the need for an increased number of trains using electricity or alternative drives. They suggest making a good analysis of the infrastructure to use hybrid trains or to use alternative drive trains [5]. In Italy, they would like to make a hybridization of vehicles that are used on the rail line Aosta-Torino. This line included electrified and non-electrified parts. They obtained the hybridization by replacing one of the four diesel generators in the vehicle with a battery module, which may ensure the full-electric mode of the vehicle [6].

Barbosa emphasizes the efficiency of building and using catenaries on small frequency lines. Catenary had good efficiency and usability if constructed on the middle and more frequency lines. To use hybrid traction technology on other lines, it is needed to do new analyses of hybrid traction technology [7]. Yizhe et al. developed a simulation to compute energy consumption, journey time, and the simulation of multi-mode trains. They were focused on converting diesel trains to hybrid or electric trains and minimizing economic costs [8]. Abdurahman´s study focused on comparing continuous electrified lines and electrified lines per part. The comparison was based on two aspects: ecology and economy [9]. A similar analysis was done by Hoffrichter et al. in Great Britain. They solve the problem by using the model with three variants: electrified lines, non-electrified lines, and electrified lines, when the catenary is not included in tunnels or places where it is very difficult to build the catenary. They are thinking about three types of trains: electrified trains, non-electrified trains, and hybrid trains [10].

3 Electrified and non-electrified rail lines in Europe

Modernization and electrification of railway lines are in progress in Europe. The number of electrified railways increases every year. In Figure 1, we can find a comparison of electrified and non-electrified railways in the EU. From 2017 to 2021, only 1% of railway lines were electrified, which is a small number [11].

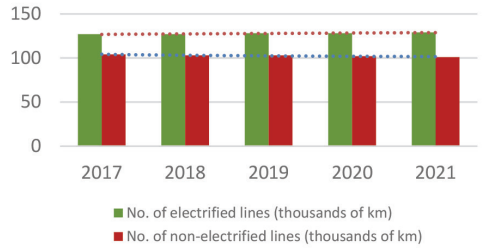

Figure 1 Electrified and non-electrified railway lines in EU [11]

In 2021, 56% of the total network length in the EU was electrified. The most electrified routes by length were in Germany, but it was only 60% of the total length of routes. After Germany were France, Italy, and Poland. There are approximately 60–70% electrified routes. The percentage of electrified and non-electrified routes is the best in Switzerland, where all routes were electrified. After Switzerland, Luxembourg, and Belgium, there are more than 88% of routes that are electrified.

On the opposite side was Ireland, where there were only 3% of electrified routes. Before Ireland, Latvia, and Lithuania, there were only 8–12% of the total route length electrified. Germany and Finland had a share close to the average of the EU. Kosovo had all routes non-electrified. Some of the countries had a better percentage than a year before. It was Poland, Germany, Spain, and Bulgaria that built electrification on their rail networks [11].

The share of electrified trains in various countries has good value. Electrified trains prevail over non-electrified trains, as can be seen in Figure 2 [11]. This share was calculated based on the intensity of use of railway lines by electrified trains on electrified lines and diesel trains by trains on non-electrified lines.

The best situation is in Sweden. There are 94% of services implemented by electrified transportation. Next to Sweden are Greece, Italy, and Finland. Services in these countries range from 88% to 85%. On the other side are countries where there are so few services implemented by electric trains. Shares in Lithuania, Luxembourg, Estonia, and Romania are only 53% to 68%. From the available data in every country, more than 50% electrified train services. The main increase was in Poland, Germany, and Bulgaria, with small numbers in other countries.

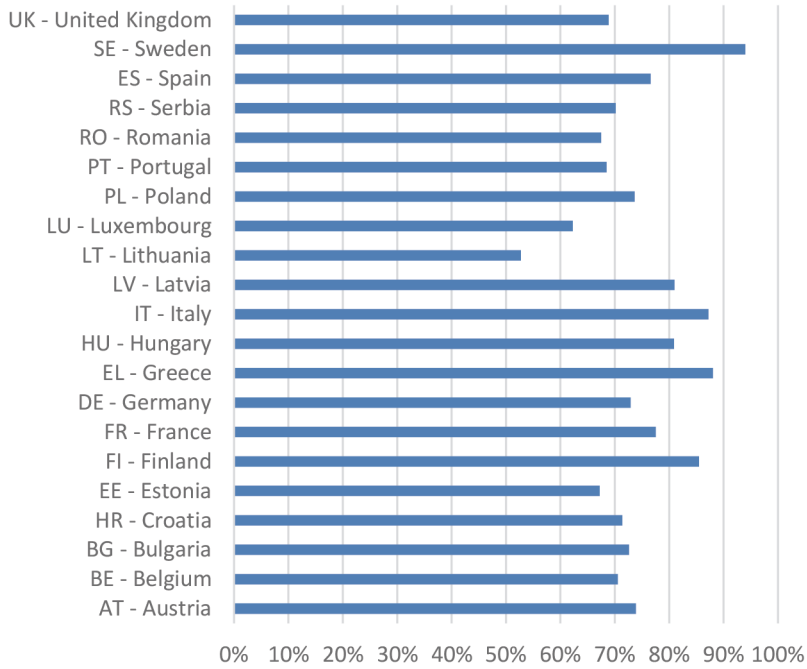

Figure 2 Share of electrified train kilometers in EU countries

4 Situation in the Slovak Republic

The electrification of railway lines in the Slovak Republic is taking place at a slow pace. In 2012, 44.06% of the railway lines in operation were electrified; in 2022, only 44.27%, while the performance of freight transport is significantly higher on electrified railway lines.

4.1 Development of transport performance in railway passenger and freight transport

The share of electric traction transport performance in passenger transport has a steady tendency, as can be seen in Figure 3 [12]. The share was calculated based on train kilometers.

Figure 3 The share of performance on electrified railway lines in passenger transport in the Slovak Republic

It is a positive phenomenon that in 2023 there was an increase in performance in passenger rail transport on electrified rail lines. Compared to 2022, performance in 2023 on electrified tracks increased by 2.668 million. train kilometers. In freight rail transport, the share of performance on electrified lines is even greater than in passenger rail transport. In Figure 4 [12], shares on electrified rail lines were calculated from performance in train kilometers, similarly to passenger transport.
In the case of performance in gross ton kilometers, the share of rail freight transport performance on electrified lines is even greater; in 2012, this share was 88.35%, and in 2023, it is up to 93.39%.

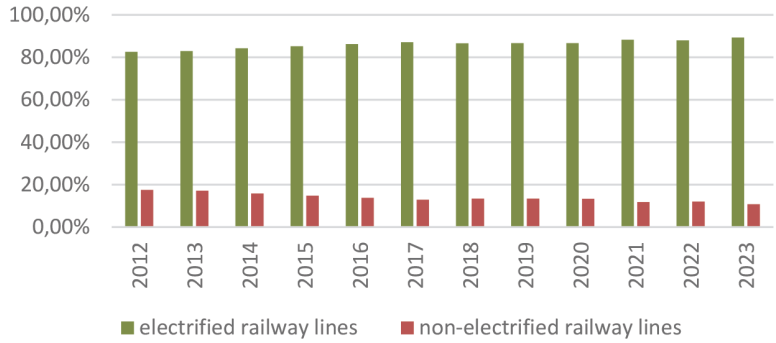

Figure 4 The share of performance on electrified railway lines in freight transport in the Slovak Republic

4.2 Comparison of the social costs of electric and diesel traction

Internal and external costs (social costs) are significantly different for electric and diesel traction. In terms of internal costs, electric traction is more efficient than diesel traction. The costs of electric traction are lower in comparison with diesel traction in these cost items:

- The costs of the total consumption of the electricity (or diesel oil)
- The fees for using railway infrastructure
- Write - offs
- Periodic maintenance (either depending on the period of vehicle use or the lifetime mileage of the vehicle)
- Scheduled maintenance (regular technical inspections, defect controls, etc.)
- Emergency repair and maintenance (in the case of vehicle damage in accidents)
- Regular repair and maintenance (e.g. cleaning and disinfection of the vehicles) [13].

Internal costs are per carrier because they depend on many factors, such as the efficiency of the use of locomotives and wagons, the organization of work, etc. In our study [13], we showed that up to 45% of internal costs can be saved if electric traction is used. They investigated how the costs of electric and diesel traction for a model train change, while we were based on real conditions in the Slovak Republic.
From the point of view of external costs, it is important to know the performance performed by electric traction. In the Slovak Republic, 10.22% of passenger transport performance and 9.53% of freight transport performance were realized by diesel traction on electrified lines in 2023. Compared to 2015, there was an increase in diesel traction performance on electrified lines in passenger transport by 3.87% and in freight transport by 0.03%.

Table 1 shows the external costs of rail passenger and freight transport by traction for the year 2022. Because the average external costs are calculated for transport performance in passenger km and ton km, and we did not have this data available by traction, we used data on the average train load in passenger and freight transport and approximated it for diesel and electric traction based on performance in gross ton km. The rates of external costs (AEC) for electric and diesel traction were taken from methodology [14], while the rates for Slovakia were considered. Given that the methodology contains rates from 2016, they were recalculated for 2022 based on the CPI (Consumer Price Index). The rates of external costs (AEC) for electric and diesel traction were taken from methodology [14], while the rates for Slovakia were considered. Given that the methodology contains rates from 2016, they were recalculated for 2022 based on the CPI.

Table 1 Performances and external costs of electrified and diesel traction in the Slovak Republic

Type of transport	mil. train km	mil. passenger km or mil. tonnes km	**AEC**	**TEC**
			€/pkm or €/tkm	mil. €
Passenger transport				
electrified traction	20,56	2 837,30	0,0559	158,74
diesel traction	14,16	835,57	0,0812	67,84
Freight transport				
electrified traction	12,10	8 454,41	0,0109	92,55
diesel traction	3,17	1 167,56	0,0348	40,68

Notes: AEC - Average external costs, TEC - Total external costs

5 Conclusion

Rail transport, like other modes of transport, must contribute to the objectives of the European Green Deal. One of the ways to contribute to this goal is to increase the share of performance by using electric traction. As can be seen from our research, external costs are more than doubled when using diesel traction in the Slovak Republic.
The European Union currently spends considerable financial resources on the use of alternative energy sources. In our further research, we deal with this issue from the point of view of the decision-making process at the level of the state and the manager of the railway infrastructure, namely when it is more profitable to electrify the railway line and when to use alternative energy sources.

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